Diamond Turned Super Alloy Mandrel for Slump Forming of X-Ray Observatory Mirrors

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John M. Casstevens

Dallas Optical Systems, Inc.

972-564-1156

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OUTLINE

- CONCEPT AND GOALS
- DIAMOND TURNING OF SLUMPING MANDRELS
- SUPER ALLOY METALLURGY AND TESTING
- SUMMARY

Development Plan

--- Investigate the properties, availability, cost and overall suitability of super alloy materials for mandrels used to slump form borosilicate glass x-ray mirrors.

--- Demonstration of the use of a diamond turning machine followed by polishing as a method of producing a high quality optical contour on super alloy materials. ENi plating investigation.

--- Fabricate and test super alloy mirrors to evaluate dimensional stability and oxidation resistance under repeated cycling at 600C in air.

--- Design a prototype super alloy slumping mandrel to be fabricated and tested in a Phase II SBIR.

Materials and Manufacturing Technology

The IXO Wolter-I x-ray telescope requires over 14,000 very thin glass grazing incidence mirror segments in 3.2 meter diameter assembly. The thin borosilicate glass sheets are slump formed on highly polished mandrels.

Diamond turning has been utilized to produce X ray and synchrotron radiation grazing incidence optical components for many years. The glass slumping mandrels required for IXO would be segments mounted on a 3 meter diamond turning machine so that multiple mandrels of a particular radius and contour can be produced at one time.

Because diamond turning can produce mandrels with extremely repeatable contour accuracy, the process allows manufacture of mandrels which can be adjusted in dimension to compensate for the thermal expansion of the borosilicate glass and the mandrel so that the curvature of the slumped glass can be adjusted. Any number of slumping mandrels can be produced with exactly the same contour with repeatability of approximately 1/100 wave visible light. This uniformity and rapidity of production of a relatively low cost mandrel will be enabling technology for IXO mirror fabrication.

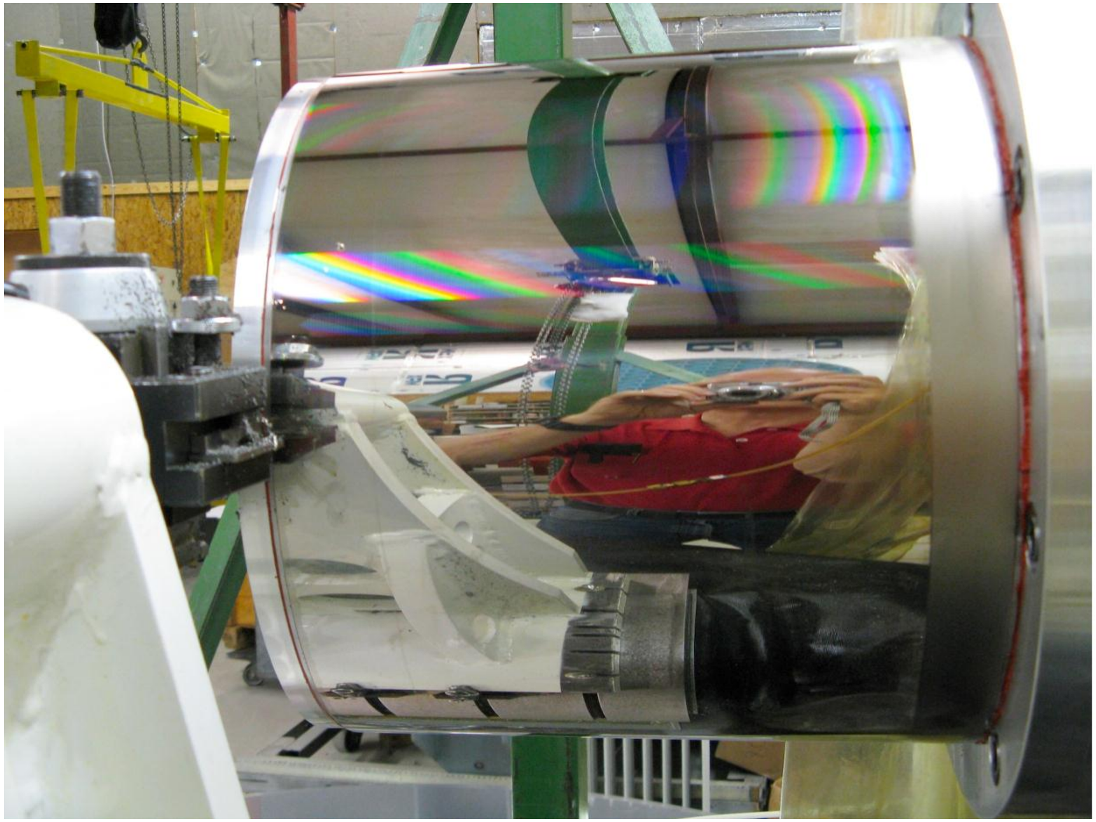
The use of ultra precision turning to produce glass slumping mandrels meeting the 5 arc second requirement of the IXO means that the mandrel material must meet a number of property requirements as follows:

- **Very high dimensional stability under repeated cycling to 600 C.**
- **Very high resistance to oxidation under repeated cycles of heating to 600 C.**
- **Machineable with diamond or other cutting tools to extreme dimensional accuracy.**
- **Suitable for polishing to extreme smoothness**.

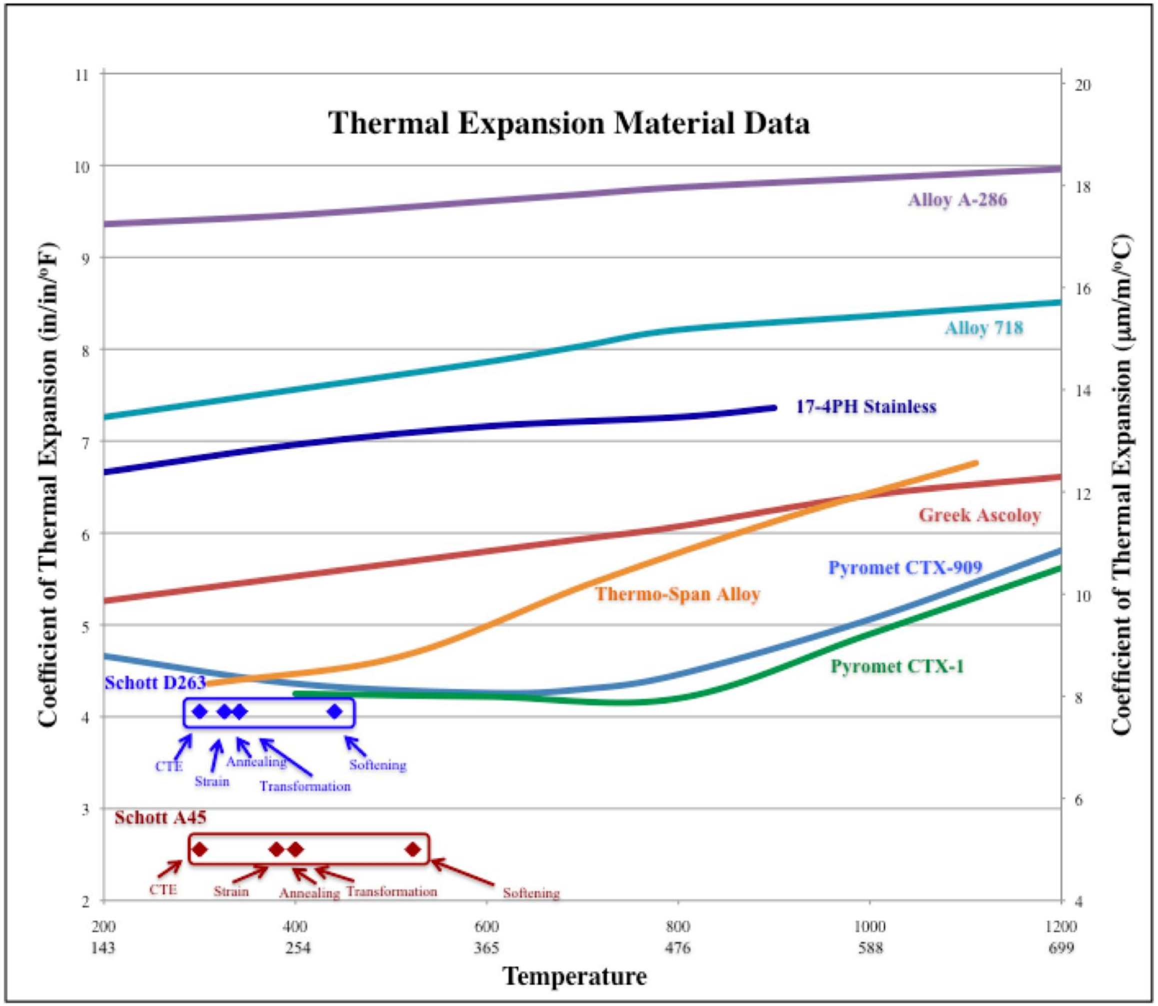
Super alloys have been under intensive development for use in turbine engines since WWII; designed for exceptional dimensional stability, creep resistance, high strength and extreme oxidation resistance under continuous cycling to temperatures as high as 900C. Hundreds of super alloy metallurgical compositions have been developed to meet a wide range of mechanical, environmental and high temperature requirements.

Diamond Turned Slumping Mandrel Test

Electroless nickel plated 17-4PH Stainless Steel



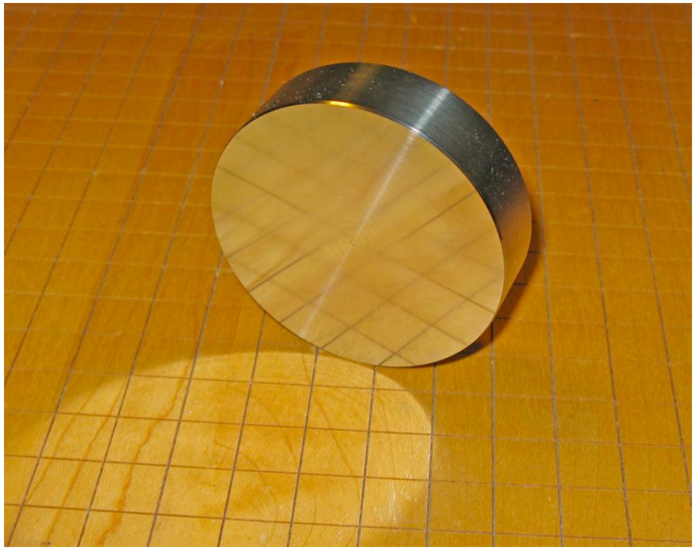
Comparison of Super Alloys and Schott D263 and A45



Chemistry Of Some Heat Resistant Super Alloys

Alloy group	Material	Hardness HV		Approximate contents in %											
		Ann.	Aged	Ni	Cr	Co	Fe	Mo	W	Nb	C	Mn	Si	Al	Ti
Nickel CMC 20.2	**Inconel 718**		425	52,5	19,0	1,0	19,0	3,0			0,04	0,4	0,9	0,9	0,9
	Inconel 706		285	42,0	16,0		40,0				0,03	0,2	0,3	0,4	1,8
	Inconel 625	200		62,0	21,5		5,0	9,0			0,04	0,5	0,5	0,4	0,4
	Hastelloy S			67,0	16,0		3,0	15,0			0,02	0,5	0,4		
	Hastelloy X	160		47,0	22,0	1,5	18,0	9,0	0,6		0,10	1,0	0,5		
	Nimonic PK33		350	55,9	18,0	14,0	0,5	7,0			0,05	0,3	0,3	2,1	2,2
	Udimet 720			56,0	16,0	14,7		3,0	1,3					2,5	5,0
	Waspaloy			58,0	19,0	13,5	0,8	4,5			0,07	0,1	0,1	1,4	3,0
Iron CMC 20.1	**Greek Ascoloy**		300	2,0	13,0		80,0	0,2			0,15	0,4	0,3		
	A286		300	25,5	15,0		56,5	1,3						0,2	2,0
	Incoloy 909			38,0		13,0	42,0			4,7			0,4		1,5
Cobalt CMC 20.3	**Haynes 25**			10,0	20,0	51,0	3,0		15,0		0,10	1,5	0,4		
	Stellite 31	280	340	10,5	25,5	56,0			7,5		0,50				

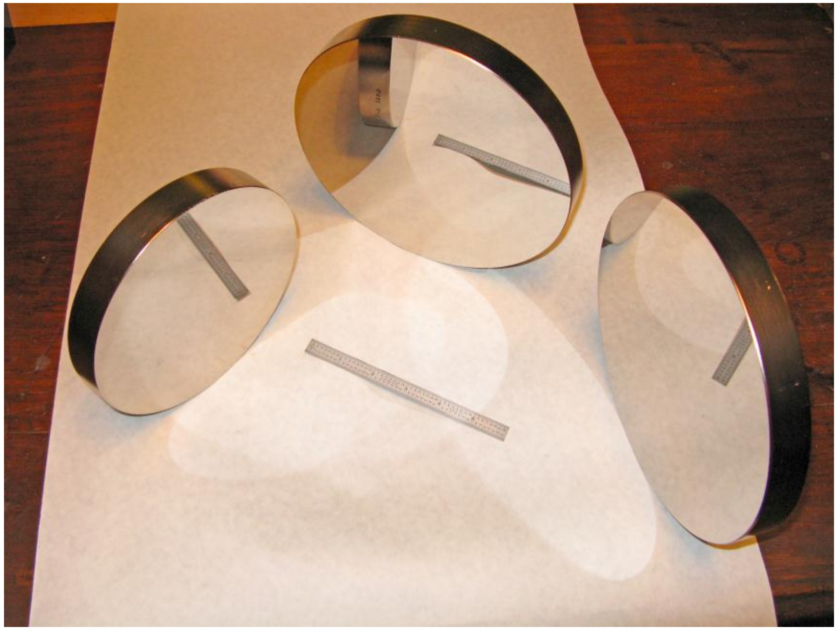
Carpenter Alloy 718PM test mirrors after conventional machining and after optical polishing



Alloy 718PM as machined

Alloy 718PM test mirrors

Mirrors 17-4PH, Pyromet CTX-909, Pyromet CTX-1 plated with Electroless Ni and polished



As plated with ENi **Polished Mirrors**

Glass Slumping Heat Cycle And Heat Cycle Testing Plan

GSFC glass slumping process

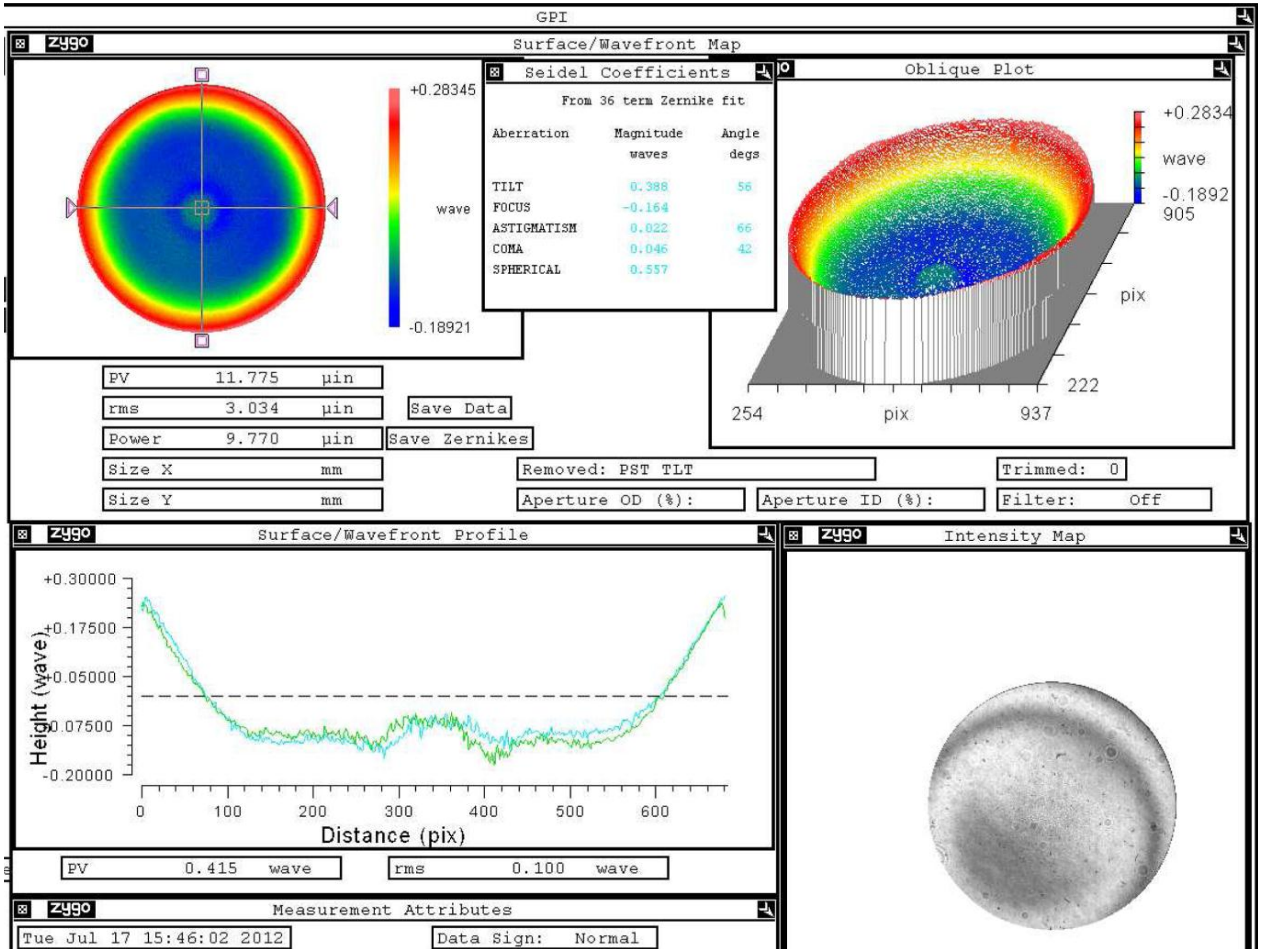
- Heat glass on mandrel RT to 600 C - 3 hours.
- Hold at 600 C - 3 hours.
- Furnace cool 600 C to RT - 20 hours.

Super Alloy Mirror Heat Cycle Testing Plan

- Heat test mirrors RT to 600 C – 2 - 3 hours.
- Hold at 600 C - 8 hours.
- Turn off, furnace cool, 600 C to RT – 8-12 hours.

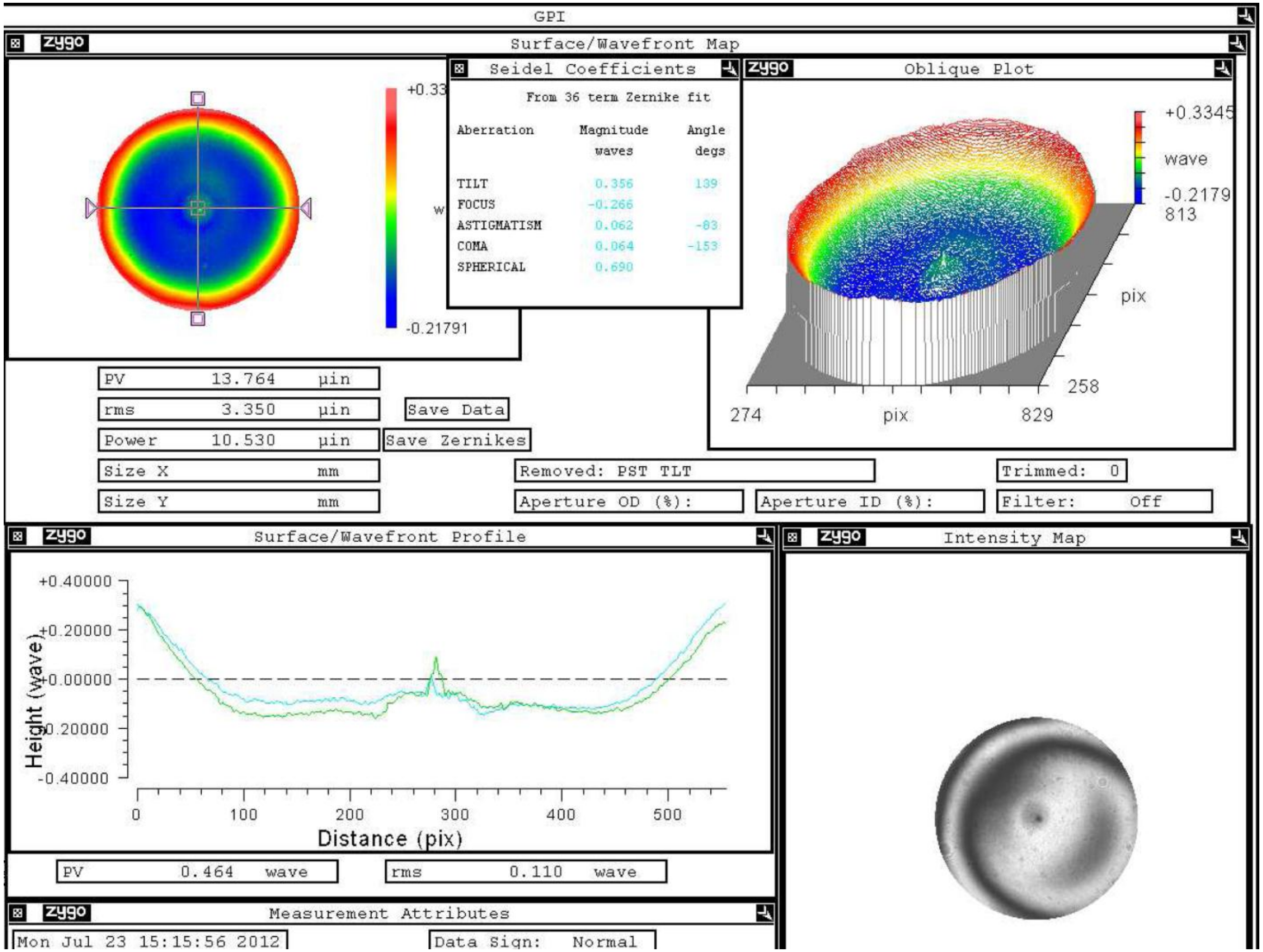
Heat Treatment Furnace Used for Slump Forming Heat Cycle Testing Mirrors

T Span Super Alloy Flatness Before Heat Cycle

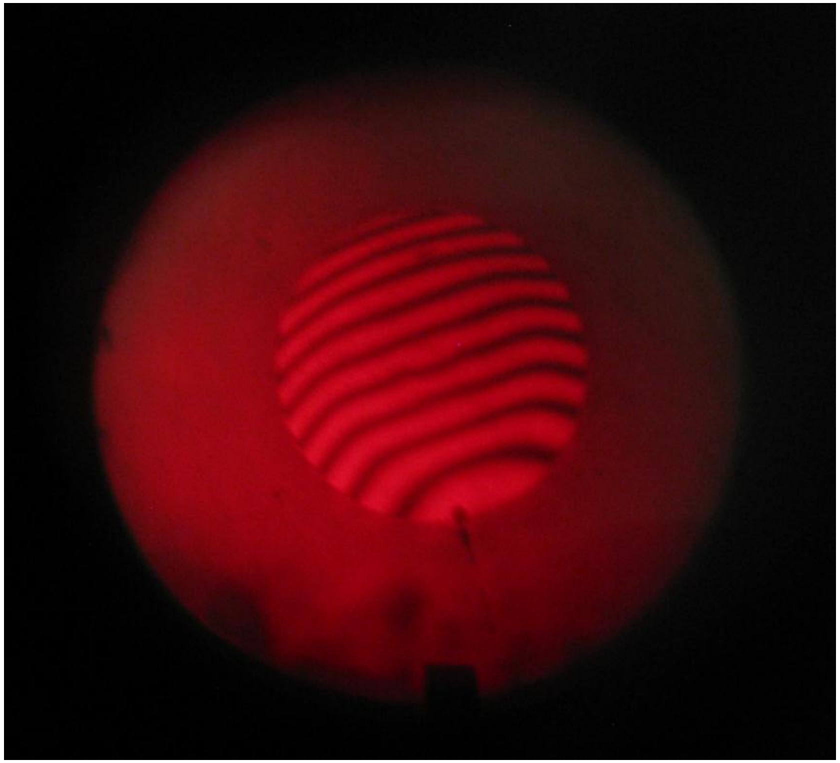


T Span Super Alloy After Heat Cycle

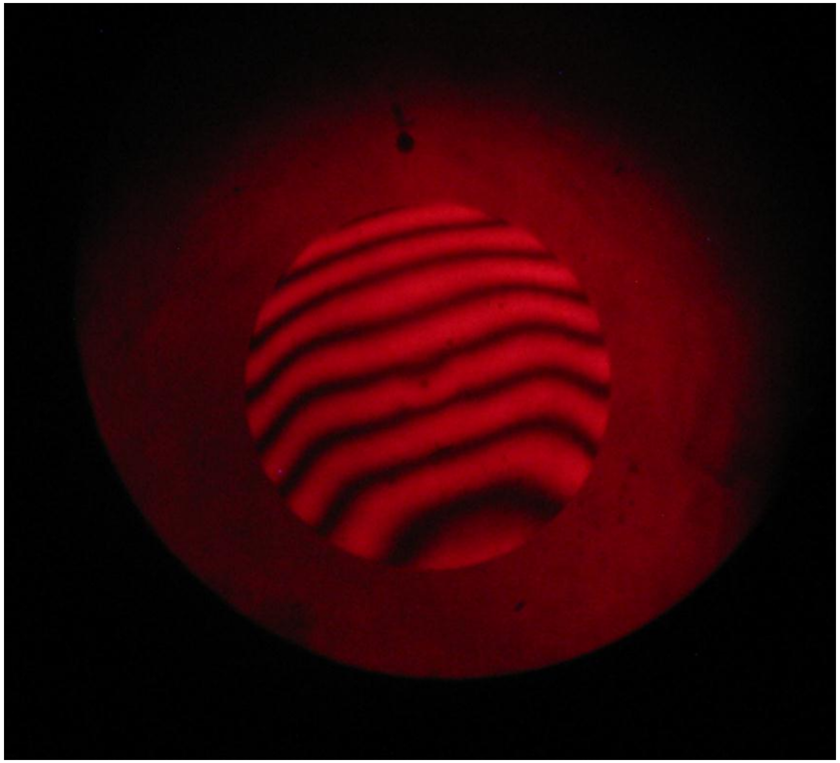
T Span Super Alloy Flatness After Heat Cycle



ThermoSpan Mirror Unchanged by 600C heat cycle

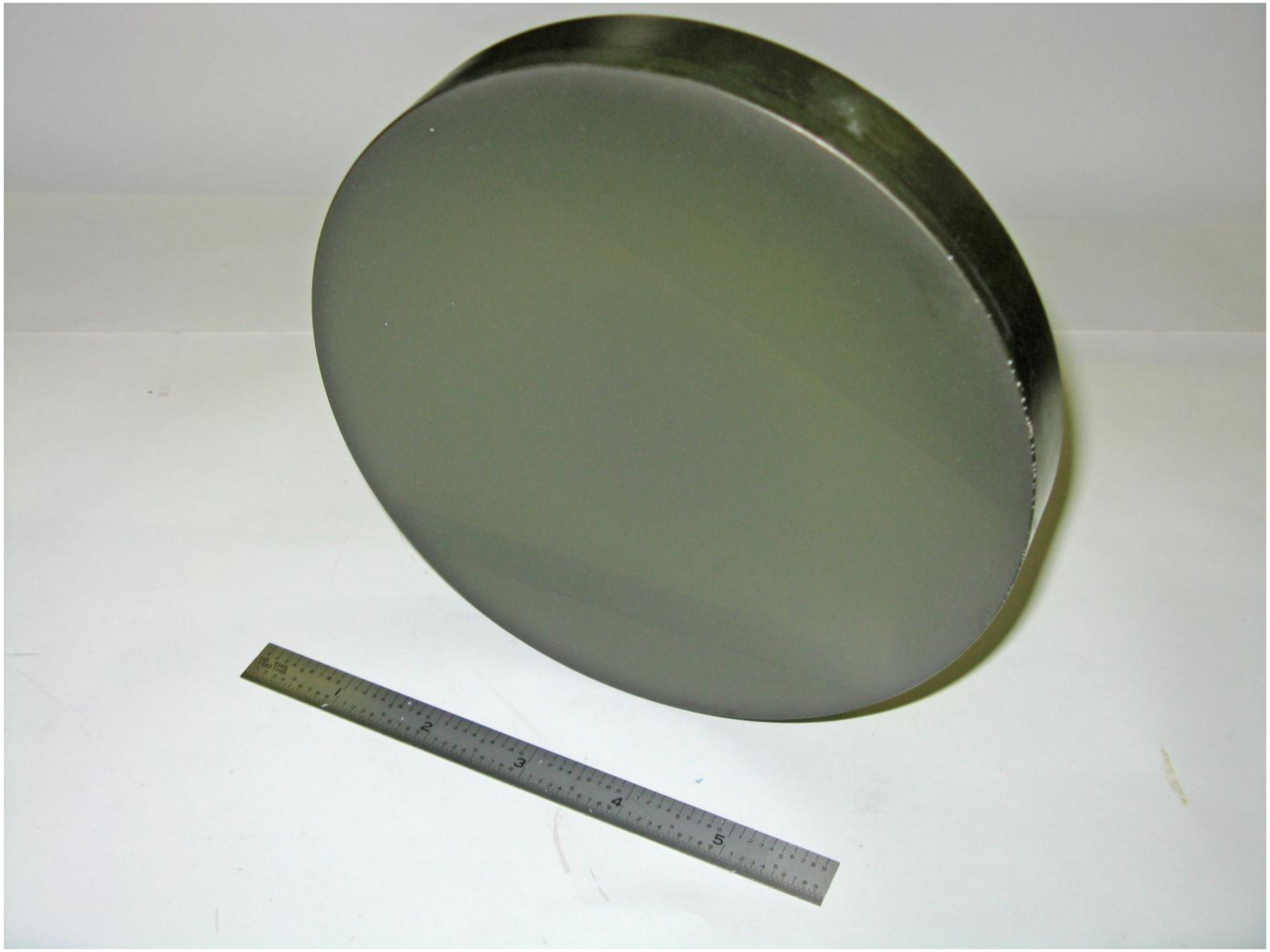


Before 600C heat cycle

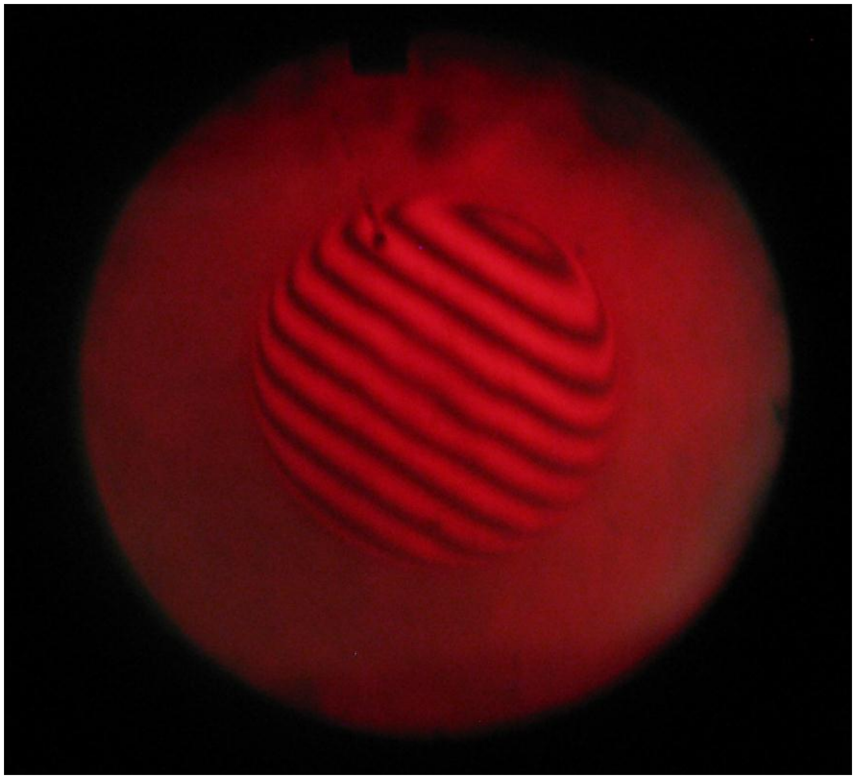


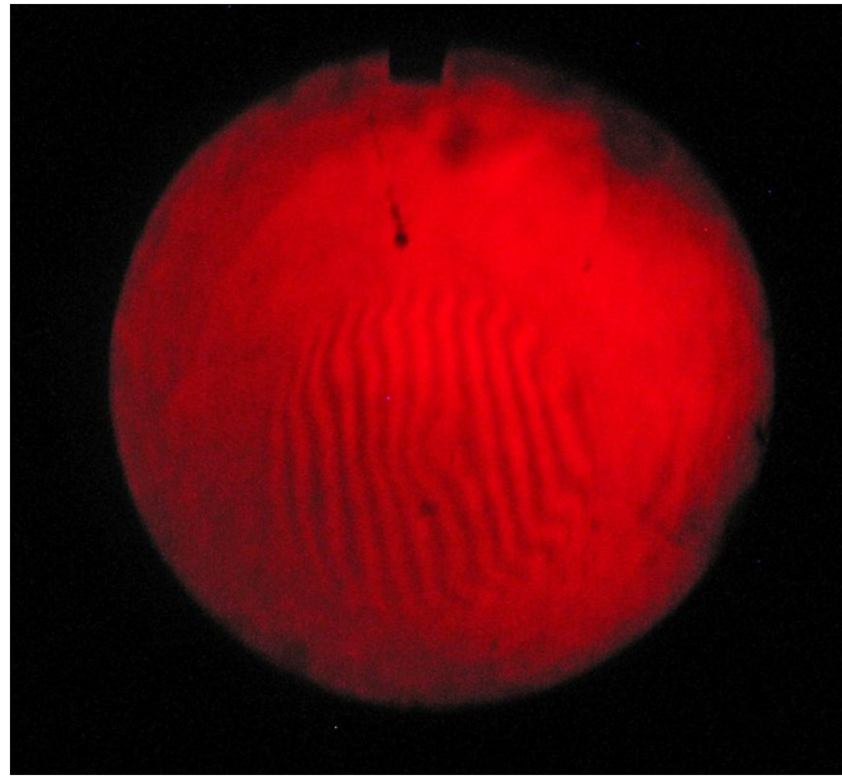
After 600C heat cycle

Electroless Nickel Plated 17-4PH SS Mirror After 600C.



Effects of 600 C cycle on E Ni Plated 17-4PH SS Mirror

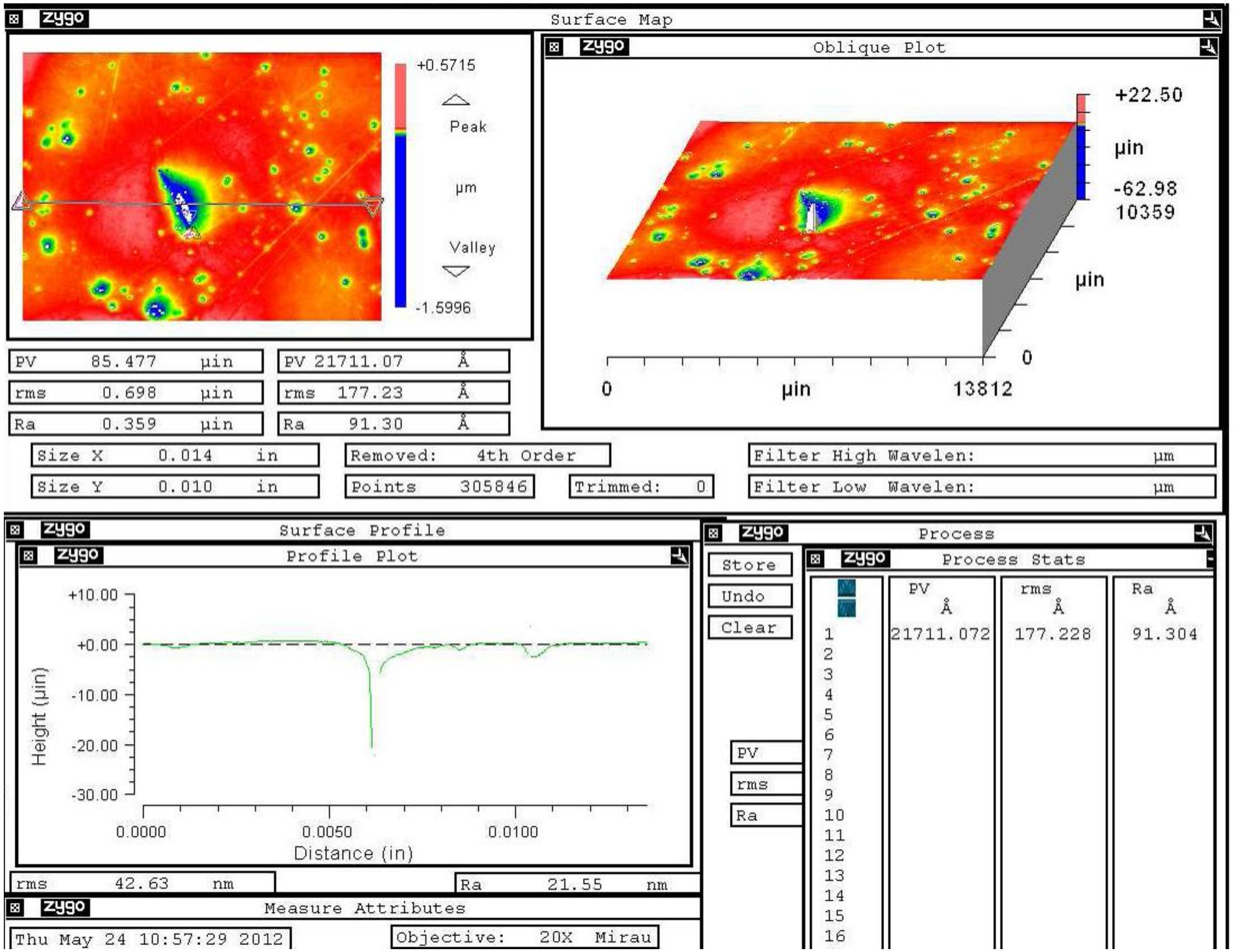




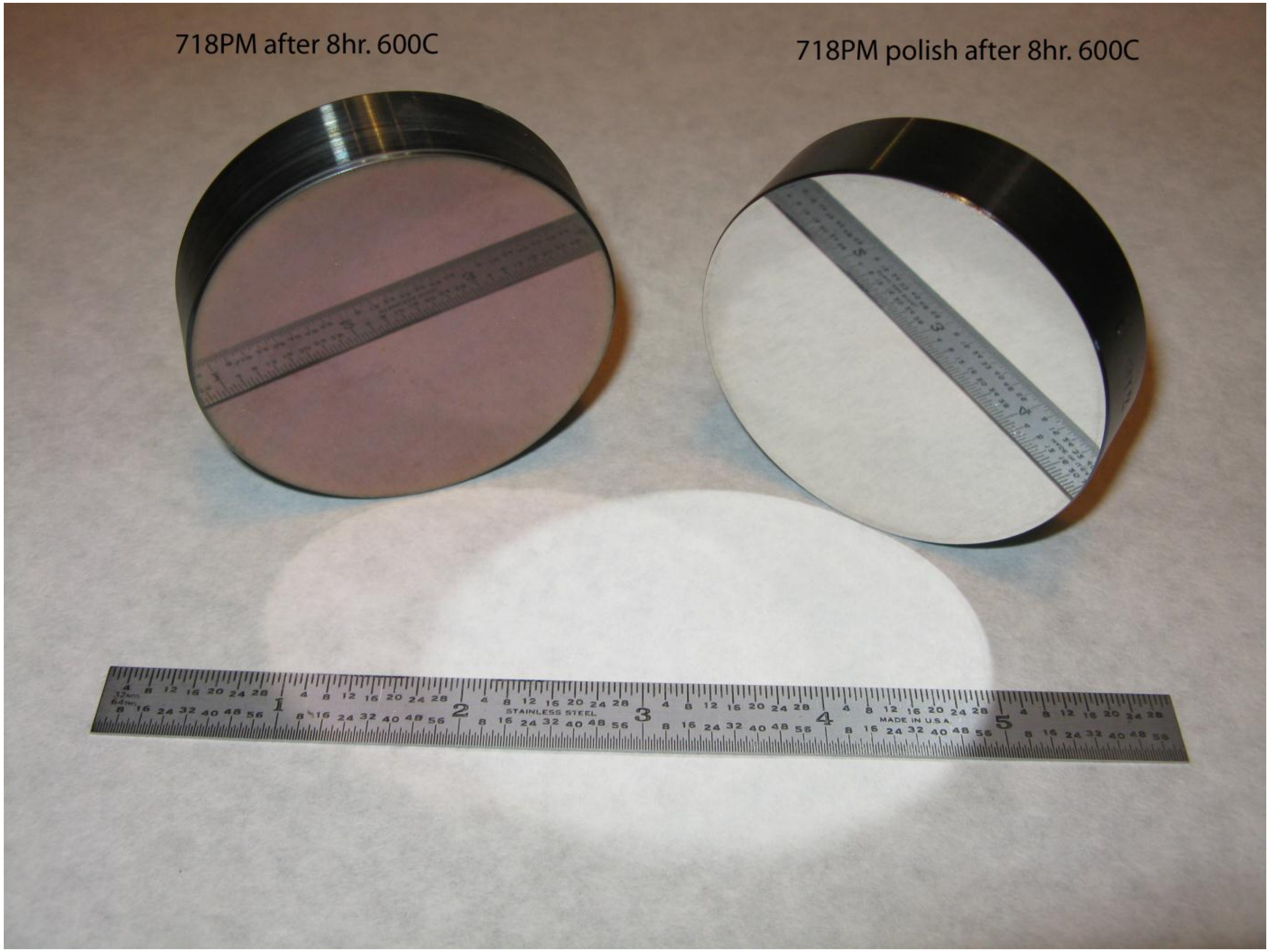
Before 600 C slumping cycle
~1/10 wave

After 600 C slumping cycle
~1/4 wave and significant oxidation.

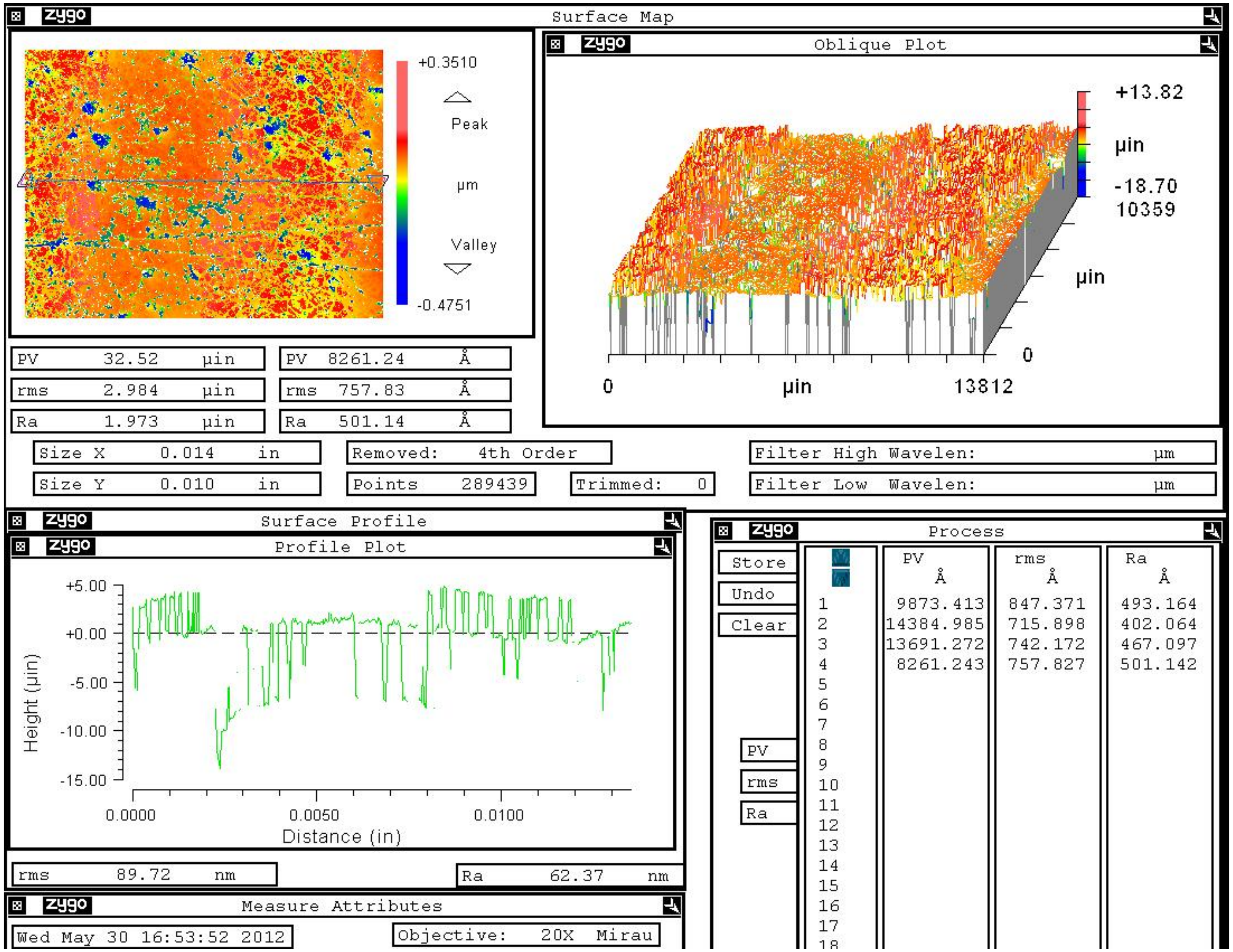
Surface Roughness 718PM Before Heat Cycle



718 PM Super Alloy Mirrors Oxide Formation



Surface Roughness 718PM After Heat Cycle



SUMMARY

- Investigated the properties, availability, cost and overall suitability of super alloy materials for mandrels used to slump form borosilicate glass x-ray mirrors.

- Completed preliminary machineability testing of ultra-precision turning and polishing as a method of producing a high quality optical contour on super alloy materials. Heat testing of electroless nickel plating indicates that unacceptable metallurgical changes and oxidation occur at the glass slumping temperature.

- Testing of machined and polished super alloy mirrors before and after exposure to the 600 C glass slumping heat cycle demonstrates outstanding dimensional stability and oxidation resistance.

- A prototype super alloy slumping mandrel to be fabricated and tested in a Phase II SBIR will require more machineability testing. Investigation of the compatibility of super alloy oxide films with borosilicate glass will be studied to address adhesion and other glass slumping issues.